Acoustic Resonance Classification of Swimbladder-Bearing Fish

Timothy K. Stanton and Dezhang Chu
Applied Ocean Physics and Engineering Department
Woods Hole Oceanographic Institution
Bigelow 201, MS #11
Woods Hole, MA 02543
phone: (508) 289-2757 fax: (508) 457-2194 email: tstanton@whoi.edu

J. Michael Jech
Northeast Fisheries Science Center
166 Water Street
Woods Hole, MA 02543
e-mail: michael.jech@noaa.gov

Award Number: N00014-04-1-0440
http://www.whoi.edu/people/tstanton

LONG-TERM GOALS

To understand and exploit the resonance scattering by swimbladder-bearing fish (typically in the 1-10 kHz frequency region). Exploitation of the resonances can significantly reduce ambiguities in interpreting acoustic scattering in terms of meaningful biological parameters compared with traditional higher frequency approaches.

OBJECTIVES

To conduct a new class of quantitative acoustic studies of scattering by swimbladder-bearing fish utilizing new commercial broadband-acoustic technology that is optimized for use in the resonance scattering region of fish.

APPROACH

This research is taking advantage of a commercial system that was originally designed for marine geological and gas/oil exploration. It is especially attractive for use in studying swimbladder-bearing fish because this system was optimized for use in the frequency band in which swimbladders typically resonate. The off-the-shelf sensors on the system (in particular, the transmitters and receivers) were selected and configured in a manner best suited for the fish application. The system is being used for studying distributions of fish in their natural habitat. The research is part of a NOAA/NMFS fisheries study and includes trawling for ground truthing and traditional high frequency echo sounders for comparison. Data are being interpreted in terms of physics-based scattering models whose parameters may be determined empirically as a result of the measurements. Tim Stanton oversees the entire program and is involved in every aspect. Dezhang Chu participated in finalizing system specifications, conducting the system calibration, participating in the first at-sea study, and processing the data. Cindy Sellers participated in both at-sea studies and processing the data. Mike Jech conducts the

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
2008		**00-00-2008 to 00-00-2008**

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
Acoustic Resonance Classification of Swimbladder-Bearing Fish	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Woods Hole Oceanographic Institution,Applied Ocean Physics and Engineering Department,Bigelow 201, MS #11,Woods Hole,MA,02543**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**5**	

biological sampling, performs high frequency acoustic surveys, and is involved in the design and execution of the cruises. NRL (led by Roger Gauss) participated in the second cruise to use their prototype mid-frequency system for long-range detection of fish.

WORK COMPLETED

The year spanned a wide range of activities, including testing the repaired replacement acoustic system, working on research manuscripts, data analysis of the September 2007 cruise, and preparing for and conducting the September 2008 cruise. One paper (broadband calibration) was published and another paper (describing the new broadband system and results of field application) was submitted.

1. Testing of repaired replacement system. When the system was replaced one year ago, it had an unacceptably high noise level. Over this winter, the system was repaired and the dockside tests and field application showed the noise levels to be very low, permitting acquisition of high quality echo data.

2. Research manuscripts. There was significant activity on two refereed journal articles this year, one involving the new calibration method we developed for broadband systems (submitted last year) and one involving describing the entire system and applications to studying fish (submitted this year). The reviews to the calibration manuscript requested improvements to the manuscript, which were made, and the manuscript was subsequently resubmitted, accepted, and published. The system/application manuscript described the entire approach, including concept of the resonance classification system, choice of hardware, development of software, calibration procedures, field use, and interpreting data in terms of meaningful biological parameters (fish type, size, and numerical density). The analysis and draft figures for another manuscript describing a new acoustic scattering model for swimbladder-bearing fish were presented at conferences this year and will be made into a manuscript for submission in the coming year.

3. Data analysis of September 2007 cruise. Echo data from two different regions, Georges Bank and Jeffreys Ledge, were examined. Echograms from selected transects in each region were produced and frequency response of the densest patches was calculated. These data were then analyzed under another ONR grant in order to characterize the statistics of the patch dimensions and looking for patterns in the statistics both within and across regions (see more details in “Related Projects”).

4. Preparation for September 2008 cruise. This cruise was more complex than the 2007 cruise, as it involved two ships (versus one last year) as well as two mid-frequency acoustics groups on our ship (versus one last year). Stanton was Chief Scientist and coordinated preparations within his ship (Endeavor) and between ships (the other ship was the Delaware II). The other group on the Endeavor was lead by Roger Gauss of NRL, who was to use their long-range active broadband mid-frequency sonar on the cruise. Preparation included dock testing of the WHOI broadband active system (mid-frequency), integration of Endeavor tow winch with WHOI system (which involved shipping the winch system to WHOI for integration and testing), testing of the NRL towed array at WHOI, and repairs to various components of the NRL system.

5. Conducting September 2008 cruise. This was a two-ship experiment over Georges Bank, about 100 miles off Cape Cod, MA. The work focused near the NE corner of the bank near the 200 m contour. The WHOI/NRL team was on the R/V Endeavor and the NMFS team was on the FR/V Delaware-II.

The Endeavor activities principally involved use of two mid-frequency acoustic systems—the WHOI broadband system that looked in the downward direction and the NRL broadband system that looked horizontally. The Delaware-II activities principally involved studying the distributions of fish using downward looking narrowband high frequency echosounders and using nets to sample the fish. The NRL system was deployed principally during the day and the WHOI system was deployed principally at night, collectively making up a full 24-hour day of measurements each day. Activities of both ships were coordinated via ship-to-ship communication (radio and e-mail) so that acoustic echoes measured by the WHOI and NRL systems could be "ground truthed" via net sampling on the Delaware-II.

A "hot spot" involving dense aggregations of fish was immediately discovered at the first station and the majority of the activities of the 10-day cruise focused on that area (Fig 1). Other areas within the NE region of Georges Bank were also studied with the two ships. In addition to the science phase of the cruise, the downward looking systems from each ship were calibrated at sea. The NRL system will be calibrated at Seneca Lake in October 2008.

RESULTS

1. Performance and demonstrated capabilities of WHOI broadband mid-frequency system. The WHOI broadband active acoustic system performed the best, by far, that it ever has. This system is the replacement to the one lost at sea two years ago. The original system had a ringing effect that contaminated echoes in the 0-30 m range from the towbody. Also, due to the inherent insensitivity of the broadband transmitters, the system had to be towed deep near the fish in order to detect them. The construction of the replacement system involved isolating the acoustic transmitter from the towbody, which significantly reduced the ringing. Furthermore, the background noise was significantly smaller in the new system. As a result, the towbody could be towed near the sea surface and could detect fish throughout the water column in water depths of 200 m. This is a dramatic improvement over the previous system that needed to be towed deep near the fish. Thus, this cruise demonstrated a very capable and flexible system.

2. Observation of scattering resonances at various depths (WHOI). Resonances in the spectrum of the echoes from fish were observed throughout the water column. Our initial analysis shows the resonance frequency to vary with depth, as expected, since the resonance is caused by the swimbladder of the fish which changes shape with increasing ambient pressure (depth).

3. Observation of multiple resonances (WHOI). In at least two of the patches of fish, two resonance frequencies were observed. This is consistent with the net tows made in the same area and depth in which a mixed assemblage of fish was sampled.

4. Observation of strong patchiness of the fish (WHOI). Many aggregations of the fish were observed to be very patchy. There were also cases in which the fish resided near the bottom in long continuous shoals (Fig. 1).

5. Observation of resonance and patchiness in "bottom" echo (NRL). The initial analysis of the NRL horizontal-looking system focused on the echoes associated with the bottom. Here, the echo was observed to have resonance frequencies in the range 3-4 kHz and to be patchy (in an area where the seafloor is smooth). Patchy, in their context, refers to echoes that survive the energy normalizer,

which displays clutter only. This "bottom" echo is consistent with scattering by the Atlantic herring that were present. Patches of resonant "bottom" echoes were detected at ranges of up to 7 km.

6. Observation of pure and mixed aggregations of fish (NOAA). The net samples show a range of types of assemblages of organisms—the near-surface layers contained a mixture of krill and small fish of length 2-4 cm (butterfish and silver hake) and the aggregations at mid-water and near the bottom involved larger fish and were either pure Atlantic herring or a mix of herring and other fish (redfish, silver hake, and others). The cohesive aggregations tended to be pure herring and the dispersed aggregations tended to be a mix of species.

IMPACT/APPLICATIONS

There is potential impact in several major categories: 1) The improvements of this system over the past several years have demonstrated that resonance classification with this type of system can be performed over a wide range of conditions, including towing near the surface and imaging the entire water column and towing deep near the fish. 2) The observation of two resonances in the data associated with a mixed assemblage of fish demonstrates the utility of the system in studying complex assemblages of fish. From this type of result, the size distribution of the fish can be estimated (that is, the numerical density of each mean size class). 3) The observed depth-dependence of swimbladder resonance frequency can be used in refining existing acoustic scattering models for prediction of reverberation and interpretation of these data. 4) The observation of the resonance in the echoes associated with the bottom with the NRL horizontal-looking mid-frequency system suggests that the fish were dominating the echo. These results from the NRL system demonstrate that resonance classification of fish can be performed at long ranges.

RELATED PROJECTS

We are being funded through the Undersea Signal Processing Division of ONR to study the statistics of the fish echoes (grant N00014-07-1-0232). The data from this (Biology) program are being used in two ways: 1) The statistics of the mid-frequency echoes have been studied in relation to a combination of the patchiness of the fish and acoustic beampattern. The studies show that the echoes are strongly non-Rayleigh which may need to be accounted for in ASW systems. Several probability density functions (PDF's) have been used or developed to describe the statistics. 2) The echograms from the high frequency (high resolution) channels have been used to study the statistics of the dimensions of the patches and compared with mathematical-ecology-based predictions of patch statistics. This analysis can ultimately allow for prediction of echo statistics for Navy systems due to the combination of probability of occurrence of patches and probability of size of patches. Also, this analysis can ultimately lead to a better of understanding of fish behavior, as the type of behavior is linked to the patch statistics.

PUBLICATIONS

2008 Stanton, T.K. and D. Chu, "Calibration of broadband active acoustic systems using a single standard spherical target," Proceedings of the MTS/IEEE Oceans 08 Conference (Kobe).

2008 Stanton, T.K. and D. Chu, "Calibration of broadband active systems using a single standard spherical target," *J. Acoust. Soc. Am.*, **124**, 128-136. (refereed)

Stanton, T.K., D. Chu, J.M. Jech, and J.D. Irish, "Resonance classification and high-resolution imagery of swimbladder-bearing fish using a broadband echosounder," submitted to ICES J. Mar. Sci. (refereed)

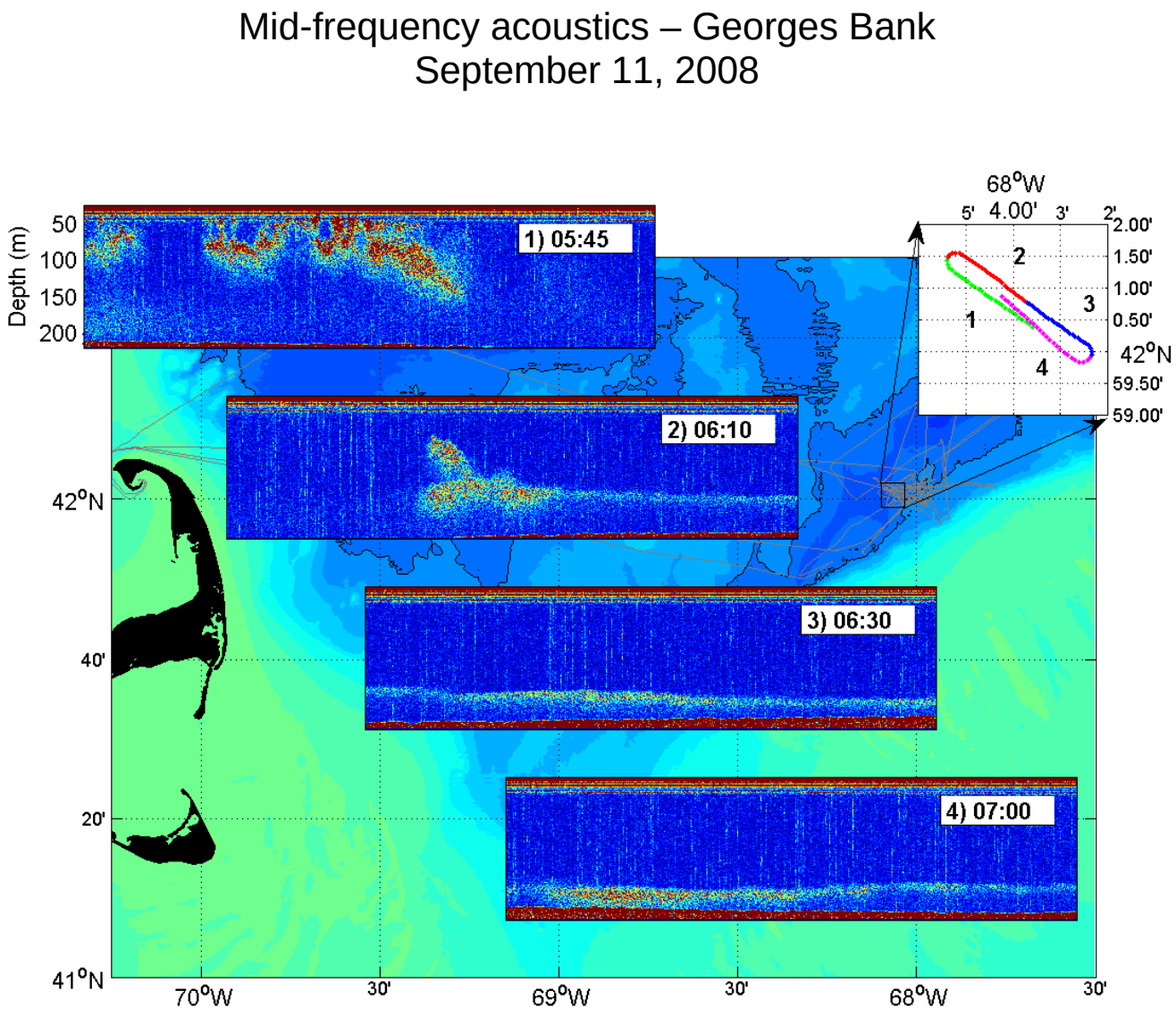

Figure 1. Echograms from close parallel transects during the diurnal migration at dawn using WHOI broadband mid-frequency active system (1.5 – 6 kHz). This series shows significant patchiness of fish in the upper water column for the early dawn transect (top panel) and the fish redistributing into long continuous shoals near the seafloor as it becomes light (lower panels). These and other data have resonances associated with the swimbladder of the fish in this mid-frequency range. The study was conducted over the NE section of Georges Bank (100 miles east of Cape Cod, MA) near the 200 m depth contour. The transects began at 0515 local time (left side of top panel) and ended at 0700 (right side of bottom panel).